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Formwork Construction Based on Finger Joint Structure

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***Abstract*:** *This paper introduces a novel method in creating formwork for concrete casting in the construction industry. The formwork of a concrete body in digital design is directly generated by a computer program in the form of two-dimensional planar parts. These parts can be fabricated by CNC cutters, such as a laser cutter. Finger joints are embedded on the edge of each part to facilitate interlocking. The end result is a construction kit that can be conveniently assembled manually for application of concrete casting.*

Keywords: *formwork, finger joint, concrete casting*

1. Introduction

Concrete casting is an indispensable process in building construction. Singapore in particular builds all of its high-rise buildings and civil infrastructure such as staircases, walkways and dikes of reinforced concrete. There are two primary approaches for concrete casting: first, casting based on system formwork for regular-shaped structures (e.g. straight wall or staircase, rectangular pillar, etc.); second, casting based on customized formwork for irregular-shaped structures (e.g. curved wall or staircase, dome, etc.).

Existing technology for making customized formwork depends heavily on skilled workers, who interpret a design by architects and make formwork parts based on experience. The fabrication of these parts are usually done on site with semi-automatic machines, such as table saws. This process is slow, labor demanding and prone to large precision errors. In this paper, we introduce a new technology to create customized formwork free from aforementioned problems.

2. Existing Approach

Existing approach for making customized formwork of irregular shapes starts from a digital model created by an architect. A builder interprets the model and fabricates formwork using manually operated tools such as a table saw and handheld nail guns. The shape and quality of formwork for each part is calculated by the builder based on his or her level of experience. The parts are then assembled manually with temporary strengthening structure, connected by screws and nails. The complete formwork has an interior volume approximately equal to the input model but due to high levels of imprecision there is large deviation in shape from the digital model. After the formwork is complete, concrete is poured and the timber structure removed. It is not possible to fabricate finishes such as surface of stone or handrail of metal in advance. All trades to follow must wait for the concrete artifact to be casted; then it is re-measured by hand and new products are built from the new measurements. Problem in this approach lies in high cost due to the use of skilled builders, low efficiency as segmentation of the digital model is based on experience, low accuracy as the parts are fabricated by semi-automatic machines, and time consuming because of the sequential workflow of various trades.

To address the problems, the current construction industry discourages architects from designing irregular shapes that cannot be casted by system formwork. Prior to construction, representatives of construction companies and architecture firms have to go through prolonged meetings to reach an agreement on the complexity of concrete structures. Sometimes irregular shapes of concrete are replaced by other materials; other times they are reduced in geometric complexity. These changes often lead to aesthetic and functional degradation of the structures.

In Singapore, it is said that international architecture firms usually have lots of design issues with local construction companies in their first few projects. With accumulated experience in construction of the region, their architects would learn to not to design irregular shapes when possible because the cost of construction in Singapore is simply very high, and there is very little space on site for making customized formwork. Without new technology, these practices will continue, leaving owners to bear with their compromised expectation of a high-cost purchase.

3. Proposed Approach

We address the challenge of making customized formwork by exploring a generative system for assembly of planar structures. We created a system that generates finger joints where two planar surfaces meet. Given a CAD model as input, our goal is to generate a constructible set of 2D parts (construction kits) with interlocking features ready for fabrication. The output of the system is a set of planar parts complete with finger joints. The system also generates corresponding parts in 3D space for visual evaluation to facilitate assembly. This is done in three steps:

(a) Planar parts are extracted from the CAD model.

(b) Connectivity of the planar parts is analysed.

(c) Finger joints are generated for each mutual edge between two planar parts.

Fig. 3. A concrete building prototype generated from the proposed technology.

In addition, the system provides estimation of time in fabrication and construction, which can be used to estimate the cost of production. Due to the generative nature of the system, repeated hand drafting is offloaded from a designer, who is freed to focus on the core design of a structure without concerning about generating the

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fabrication data. This facilitates sophisticated design ideas that can be materialized in the physical world; for example, Figure 3 shows a concrete building prototype created from the system.

We envision the technology being used in two ways, first, as a service to constructors, such as pre-fabrication companies in Singapore at the start. For these users, the technology is a mold-making method, capable of producing customized mold. A pre-fabrication company may provide the service provider a CAD model of a concrete structure; we generate construction kits of the formwork, and fabricate the parts either by in-house laser cutters or through laser-cutting service companies; then we send the pre-fabrication company the construction kits with a service charge.

Second, it can be used as a design tool for architects; in this case, we package it as a software product. Architects are creative people, who constantly explore new tools to facilitate their design. Current design tools rarely address the issue of construction, thereby leading to a deep separation between design and production. Our technology can be viewed as a bridge in between. It incorporates design elements in that CAD models are instantly analyzed; the feedback to the users is prompt: they know immediately the feasibility and estimated time of construction. It also incorporates production elements in that the architects can actually laser cut the parts and make mockup models of various sizes. The design iteration is speeded because of the instant feedback and the quality of design evaluation is enhanced through physical prototyping.

4. Novelty

The proposed approach offers design-oriented construction solutions. It aims to enable physical production directly from a digital model, offloading repeated drafting work from a designer, and simplifying structure assembly through automatically generated assembly features. In the long term, the approach may become an indispensable step in the design-construction process, providing prototypical design feedback and accurate estimation of construction time.

Our research focuses on computational algorithms for generating the finger joints. The algorithms not only generate joint shapes along a mutual edge between two faces, they also generate the shape of a vertex shared among multiple faces. This is to ensure an exact representation of the input model.

The novelty of our work in application to formwork production is summarized in three points:

1) Generation of the construction kits of the formwork is completely based on the CAD model, thereby the shape of kits is much more accurate that that generated by a human based on past experience,

2) Fabrication of the construction kits is done by digital manufacturing machines, thereby high precision is guaranteed,

3) Assembly of the kits is facilitated by the finger joints, thereby saving time and effort in the manual assembly process.

With these advantages, our technology is potentially lower cost, more efficient, and easier to execute than the conventional approach of making customized formwork.

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